Slow light induced by Stimulated Raman Scattering on spatial Kerr soliton

Jeremy Michaud, Gil Fanjoux, Hervé Maillotte, Luca Furfaro, Thibaut Sylvestre

To be published in Ann. Phys. Fr. 2007

Slow light induced by stimulated Raman scattering on spatial Kerr soliton

J. Michaud[a], G. Fanjoux, H. Maillotte, L. Furfaro and T. Sylvestre

Département d'Optique P.M. Duffieux, Institut FEMTO-ST, Université de Franche-Comté, CNRS 6174, 25030 Besançon, France

Abstract

We present numerical and experimental results demonstrating the slow light effect induced by the sharp resonance of the Raman gain on a spatial Raman soliton in a Kerr planar waveguide.

1 INTRODUCTION

It is now possible to generate large optical delay of a signal pulse by generating at the signal frequency a strong dispersion associated with a laser-induced amplifying resonance, such as that arising from stimulated Raman or Brillouin scattering [1,2] (for more details about slow light see Ref. [3] and ref therein). Furthermore, if the nonlinear medium has a strong self-focusing nonlinearity, in this way it becomes possible to generate slow-light spatial solitons. Based on this idea, this work demonstrates both numerically and experimentally, for the first time to our knowledge, the slow light process induced by Stimulated Raman Scattering (SRS) on a spatial soliton [4]. This is achieved in a CS_2 nonlinear planar waveguide that possesses both a strong self-focusing nonlinearity to generate spatial Kerr soliton and a Raman susceptibility sharp enough to induce the slow light process simultaneously.

2 NUMERICAL RESULTS

We developed a spatiotemporal numerical model based on the nonlinear Schrödinger equation including the group velocity dispersion, diffraction in the free transverse dimension x of the planar waveguide, the instantaneous Kerr effect and the delayed Raman response. In our case, we consider a narrow gain band

[a] e-mail: jmichaud@univ-fcomte.fr

Raman response with a real part which induces to a sharp transition in the effective refractive index of the material. Indeed, the narrow gain band of CS_2 of 15 GHz allows for the achievement of strong group index changes at the Raman phonon frequency.

Figures 1a and 1b illustrate the longitudinal evolution of the normalized space-integrated temporal profiles for the pump and the Stokes pulses, respectively. While the pump pulse stays unchanged till 1.7 cm, *i.e.*, before the trailing edge depletion (Fig. 1a) due to the strong conversion regime, the Raman pulse evolves with three distinct steps. First, it is generated from quantum noise at the top of the pump pulse where the Raman gain is the most important. Thereafter, it undergoes a large optical delay by slowing down toward the trailing edge of the pump, up to the pump depletion regime. This delay, opposite and well greater than the walk-off due to group velocity mismatch (GVM), is unambiguously due to the slow light process. Finally, the slow light process is annihilated by the pump depletion, and the Raman pulse moves forward the pump leading edge, where the Raman gain still exists.

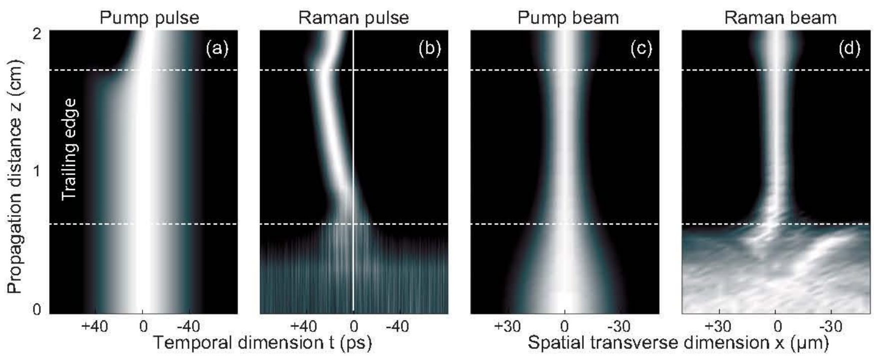

Figure 1. Numerical results: longitudinal evolution of the normalized temporal and spatial profiles of (a-c) the pump and (b-d) the Raman Stokes component in the 2 cm long planar waveguide. $P_i = 0.8$ GW/cm^2 (soliton power $P_s = 0.25$ GW/cm^2). Other parameters are $\beta_2 = +4.24 \times 10^{-25}$ s^2/m, $n_2 = +3.5 \times 10^{-18}$ m^2/W and $\lambda = 532$ nm.

Concerning the spatial dynamics, Figures 1c and 1d show the longitudinal evolution of the normalized time-integrated spatial profiles for the pump and the Stokes beams, respectively. Figure 1c shows that the pump beam first undergoes a strong self-focusing because the input power is greater than the soliton power. The Stokes beam, shown in Figure 1d, is spatially confined by the self-focused pump beam, due to both the Raman gain and to cross-phase modulation (XPM) [4]. It thus propagates with a stable spatial width till the depletion of the pump. Figures 1b and 1d together clearly demonstrate a slow-light spatial soliton, indicated by the two horizontal white dotted lines.

3 EXPERIMENTAL RESULTS

The experimental setup is made up of a 3 cm long Kerr planar waveguide made of thin liquid CS_2 layer sandwiched between two SK5 glass blocks. The pump source is a powerchip frequency-doubled Nd:YAG laser (1 kHz, 380 ps, 532 nm, see Ref. [4] for more details). The input beam spatial width is 52 μm. The pump and the Stokes beams are spatially divided at the waveguide's output end by means of a diffraction grating (2400 lines/mm) and measured both in time and in space by using a streak camera with a 5 ps resolution. Figures 2a–2c show spatiotemporal pump and Stokes beams at the waveguide's output for (a) the pump in diffraction regime, (b) the pump and (c) the corresponding Raman Stokes. Time-integrated spatial profiles are also shown in Figure 2 (bottom) and space-integrated temporal profiles (right side). By comparing Figures 2a and 2b, we observe that the pump presents a depletion of its trailing edge where the Raman Stokes (Fig. 2c) is clearly observed, in agreement with our numerical simulations. Moreover, it is noteworthy to observe that the experimental spatial profiles are perfectly fitted by the theoretical ones (dashed curves). The Stokes beam has a clear spatial soliton profile due to the fact that it is only generated when the pump reached a soliton regime. Before the pump depletion, we have measured that the time delay of the Raman pulse is linearly dependent on the input power, in agreement with the slow-light theory [5]. The maximum delay is about 120 ps for 3 cm of propagation, leading to an equivalent group velocity equal to $c/2.8$ for the Raman Stokes.

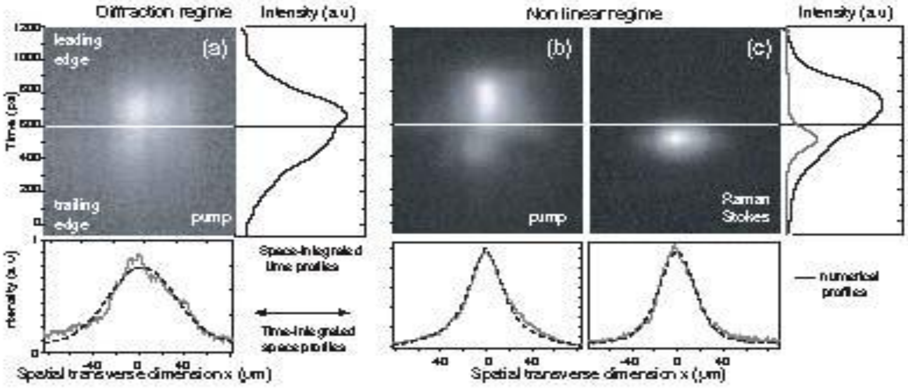

Figure 2. Experimental spatiotemporal profiles with time-integrated spatial profiles (bottom) and space-integrated temporal profiles (right side) at the waveguide's output for (a) the pump in diffraction regime ($P_i = 1$ mW), (b) the pump and (c) the Raman Stokes in nonlinear regime and at the end of the slow light stage ($P_i = 1.68$ mW). Soliton power is $P_s = 1.2$ mW.

4 CONCLUSION

We have demonstrated the slow-light effect on a Kerr spatial soliton induced by stimulated Raman scattering in a nonlinear waveguide. The Raman Stokes pulse has a 120 ps delay for 3 cm of propagation while preserving spatial soliton properties.

To be published in Ann. Phys. Fr. 2007

References

[1] J.E. Sharping, Y. Okawachi, A.L. Gaeta, Opt. Exp. **13**, 6092 (2005).
[2] K.Y. Song, M.G. Herraez, L. Thévanaz, Opt. Exp. **13**, 82 (2005).
[3] R.W Boyd, D.J. Gauthier, in *Progress in Optics 43* (Wolf Ed., Amsterdam, 2002).
[4] G. Fanjoux, J. Michaud, M. Delqué, H. Maillotte, T. Sylvestre, Opt. Lett. **31**, 3480 (2006).
[5] K. Lee, N.M. Lawandy, App. Phys. Lett. **78**, 704 (2001).